THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 54, No. 9, November 1975
Printed in U. S. A.

A Fiber-Optic-Cable Connector

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(Manuscript received May 30, 1975)

A technique has been developed that is potentially suitable for field-splicing an optical cable containing linear arrays of optical fibers. Linear arrays of fibers (which may reside in fiber ribbons) are placed between spacers that are grooved top and bottom to form stacked, rectangular arrays. This operation can be done without microscopes or micromanipulators. After potting, the ends of the two stacked arrays are polished to form cable terminations that are brought together in a butt joint splice. A 12 × 12 array using this technique exhibited a mean loss of 0.42 dB for 138 splices with 70 percent of the losses less than 0.5 dB. Subsequent single ribbon-to-ribbon splices had average losses less than 0.2 dB. Launching conditions can be duplicated and splice losses are repeatably low for reassembled splices; this presumably is due to polished fiber ends and accurate alignment. Experience gained thus far indicates that this mass splicing method will probably produce large array splices with a maximum loss of 0.5 dB.

I. INTRODUCTION

It is believed that splicing groups of optical fibers in the field will be necessary in fiber communication systems. Several investigators have successfully spliced individual fibers with various techniques.[1–4] Others have addressed themselves to splicing linear arrays of fibers.[5]

While some aspects of linear array or fiber-ribbon splicing appear applicable to cable splicing in the field, the operations must be performed for each linear array in a fiber-optic cable. Good ends must be obtained for each fiber and, although techniques for accomplishing this are evolving,[6] still these represent additional operations required for each fiber or fiber group during cable splicing. Another potential problem in applying individual or small-group splicing to a fiber-optic cable is in reassembly of the spliced ribbons into a compact spliced cable. The individual connectors would have to be very thin, and the splices would have to be the same length to effect compact reassembly.

The potential problems mentioned above stimulated investigation of another approach, cable splicing, by which we mean splicing all fibers of two cables by joining connector halves (terminations) formed on each cable end.

II. FIBER-OPTIC-CABLE SPLICING

As presently conceived, cable splicing involves the following operations:

(*i*) Aligning all fibers of one end of a fiber-optic cable into a uniform matrix.
(*ii*) Potting the structure to retain the geometry.
(*iii*) Grinding and polishing the ends of the potted array.
(*iv*) Joining two cable ends prepared by the previous three operations.

Each of these processes is covered in more detail in the following sections. An alternative approach is also presented which uses fiber ends prepared by controlled breaking.[6]

III. ALIGNMENT OF FIBERS

Several techniques have been attempted to align fibers in a linear array. Threading fibers through holes as opposed to laying fibers in grooves is in general a more difficult and less accurate method of fiber alignment. The "grooved" concept was adopted for this cable con-

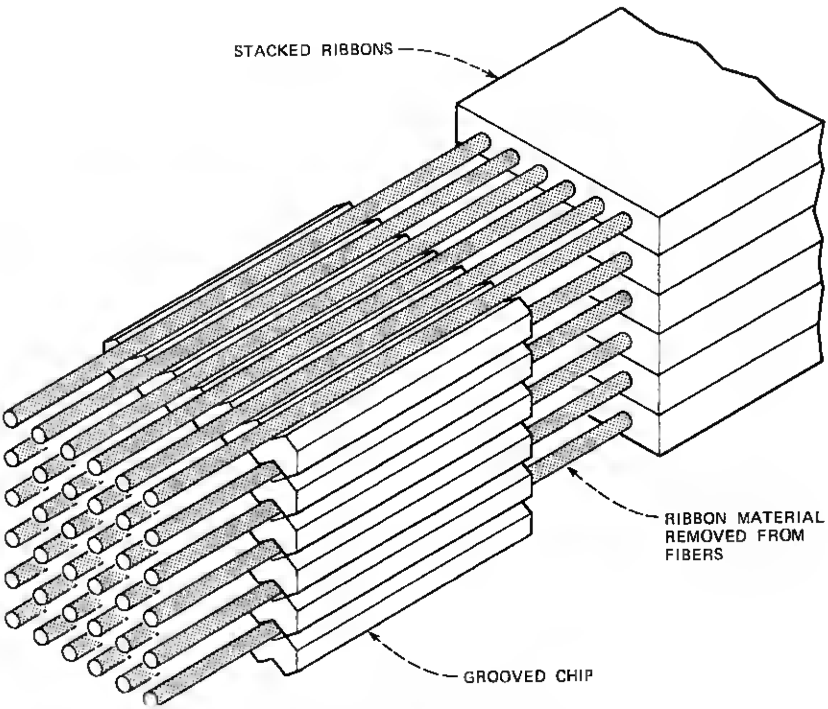

Fig. 1—Stacking fiber ribbons.

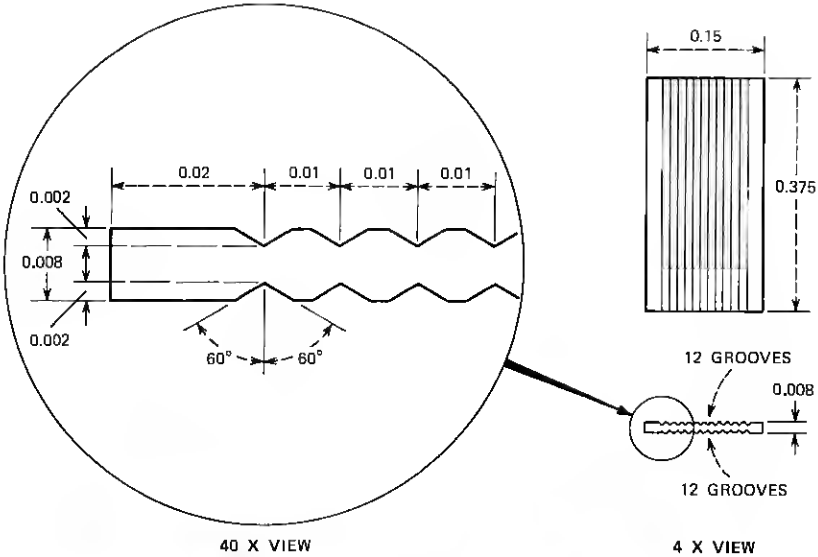

Fig. 2—Grooved chip design.

nector. Since a compact splice was desired, a thin chip design was selected which was grooved on both sides.

Figure 1 is a magnified view of how grooved chips are used to obtain fiber alignment. Ribbon ends are prepared by removing the supporting material as shown in Fig. 1. The process consists of interleaving chips and layers of fibers until all linear arrays have been stacked.

Precision grooved chips provide the primary alignment mechanism for assembly of fibers into a uniform rectangular array. These chips were produced by the Bulova Watch Company. Figure 2 is a sketch of the specifications for the chip and a photograph of the cross section of the chip. The machine work performed to make these chips was excellent. Since the chips are grooved on both sides, the top and bottom chip of the stacked array have unoccupied grooves which can be used as references for alignment during polishing and subsequently to align the two rectangular arrays in forming the butt splice.

IV. POTTING THE ARRAY

A stacked array, held by a vise, can be potted by allowing epoxy to seep through the array. Tests with close-packed arrays of fibers

showed that epoxy would seep at least $\frac{1}{2}$ inch down the length of the array before curing stops all flow. This sets the maximum length of the grooved chip; however, based on our experience a $\frac{3}{8}$-inch length appeared adequate. Approximately 15 minutes is required for epoxy to seep through a $\frac{3}{8}$-inch stacked array. Faster curing of the epoxy occurs at elevated temperatures; however, at room temperature several hours are required for the epoxy to completely cure.

A vise is used to hold the stacked array while epoxy is applied. Chips with ridges that mate with the unoccupied grooves of the stacked array will be referred to as negative chips. These negative chips are used to align the top and bottom chips of the stacked array while in the vise. Figure 3 shows the vise and the negative chips attached to the vise faces.

V. POLISHING THE ARRAY

To obtain low loss in a splice, the fiber end must be made flat and perpendicular to the fiber axis. This end preparation is usually accomplished by either controlled breaking,[6] sawing, or polishing. Sawing the epoxied arrays may yield suitable ends for splicing. Controlled breaking is not applicable to the epoxied array previously described, although polishing methods can be easily applied. Since only one polishing operation is required for each cable splice, regardless of the number of fibers or ribbons, this technique is probably the least time-consuming and the cheapest. A holding fixture for supporting and gradually advancing the epoxied array during the polishing sequence is shown in Fig. 4 with two connectors in place after polishing. The indicator at the rear of the fixture moves the inner core of the fixture (and the sample) relative to the outer cylinder. This fixture used with a grit sequence of 220×, 800×, and 0.3 μ has produced high-quality ends in approximately 15 minutes. Figure 5 shows a connector after polishing.

VI. FINAL ALIGNMENT

Several final alignment methods have been used to meet two different needs in this area. First, an alignment method has been developed for use in the laboratory in making splices that can be measured and then disassembled. Plexiglass and steel fixtures have been used for this purpose in conjunction with a grooved chip negative. These negative chips are pressed against the top and bottom of the two connectors and then placed in the final alignment fixture which further aligns the two connectors and holds them in place. This arrangement is shown in the top part of Fig. 6.

Fig. 3a—Vise used in splice fabrication.

Fig. 3b—Detail showing negative chips.

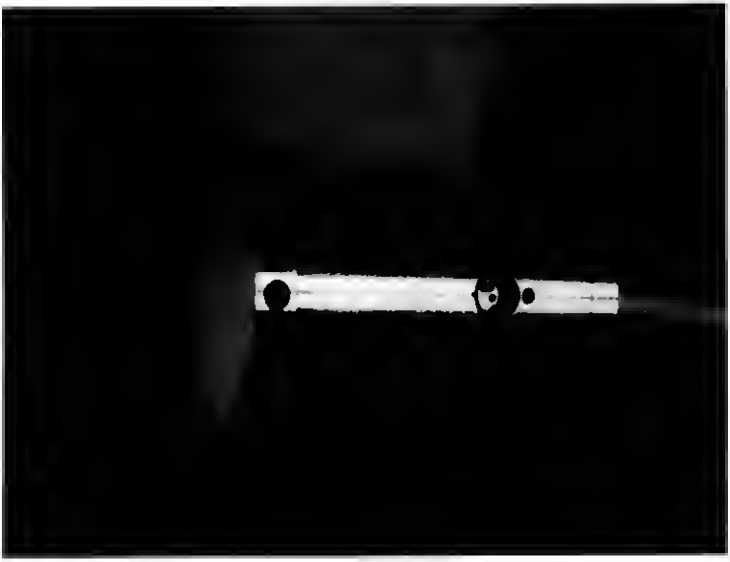

Fig. 4—Polishing fixture.

A second alignment method is used to obtain a more compact, permanent splice. For this case, the negative chips are epoxied directly onto the grooved chip connectors, again while being held and aligned

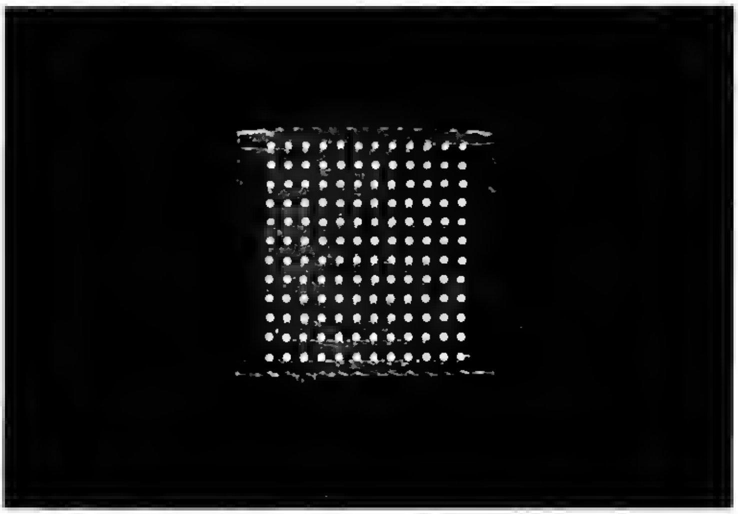

Fig. 5—End view of 12 × 12 connector after potting and polishing.

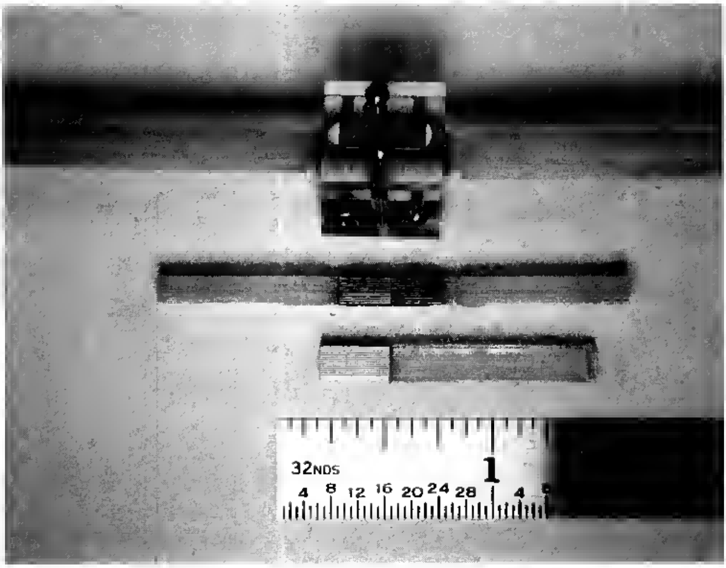

Fig. 6—Top: final alignment fixture; middle: epoxied splice; bottom: single connector.

in a suitable fixture. Figure 7 is a photograph of such a splice with index-matching epoxy used to complete splice fabrication.

VII. SPLICE-LOSS MEASUREMENTS

Using the methods and fixtures described, a 12 × 12 array splice was fabricated and measured. Six fibers were damaged or broken during the fabrication of the four connectors (connectors were placed on the input and output of the ribbon stack in addition to the splice). As shown in Fig. 8, the mean loss was 0.42 dB witb a maximum loss of 1.3 dB for 138 good splices. Seventy percent of the losses were less than 0.5 dB.

Single ribbon splices have been fabricated and measured and yield lower losses than array splices. For a typical ribbon splice with index-matching, the maximum loss was below 0.5 dB and the average loss below 0.2 dB. Crosstalk coupling between adjacent splices in a typical ribbon splice is less than −65 dB.

VIII. PERMANENT CABLE SPLICE

The fiber-optic-cable connector described thus far consists of prepared cable terminations which are joined to complete the cable splice. If a final alignment fixture is used to hold the cable terminations in place, as opposed to epoxy, the splice could be disassembled. An

Fig. 7—Splice assembly.

alternate approach[7] can be used which, although still based on the grooved-chip concept, uses a different operational sequence and no polishing and produces a splice which cannot be disassembled. This approach is illustrated in Fig. 9. Here, the fiber ends will probably be prepared by one of the methods being developed by D. Gloge[6] et al. The stacked array is fabricated in much the same way except that two

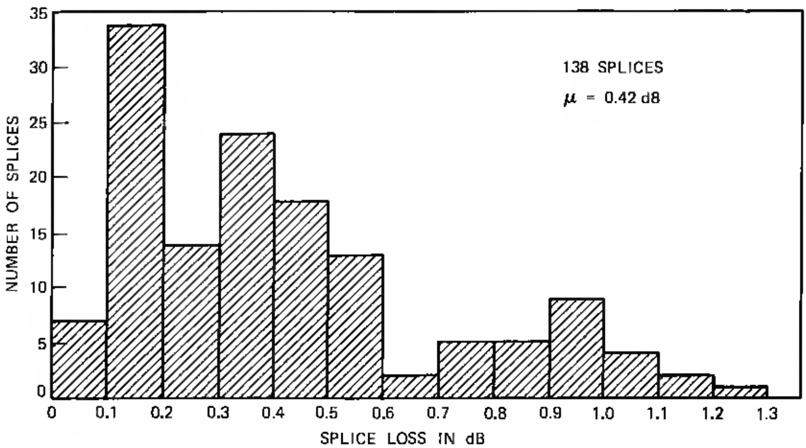

Fig. 8—Histogram of splice losses.

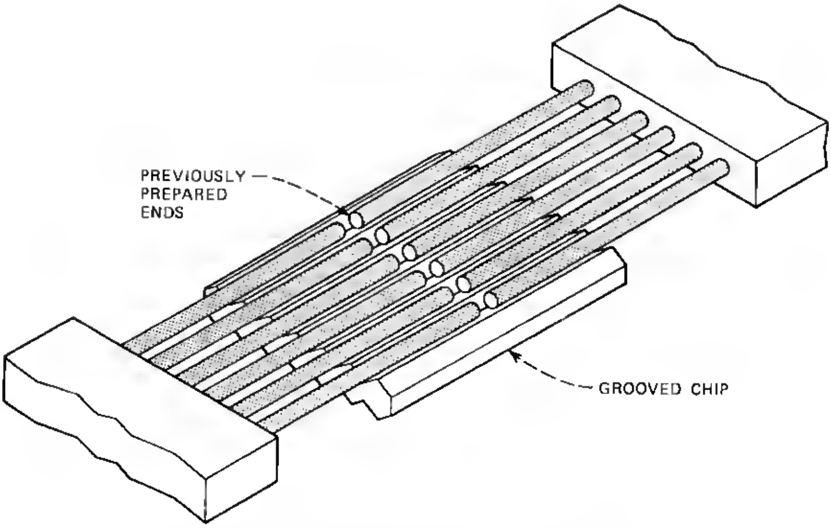

Fig. 9—Single layer of a permanent cable splice.

sets of previously prepared ends are placed in each layer. The array is then epoxied to form a permanent splice. This technique will be more difficult to assemble, and end preparation will probably be done on a ribbon-by-ribbon basis using controlled breaking. However, this permanent assembly technique should produce compact splices with losses approaching those of ribbon splices.

Some difficulties associated with ribbon splicing mentioned earlier are present in this approach. These include multiple operations required for end preparations and nearly exact ribbon length requirements. The resulting splice will, however, be small and strong, and should easily meet the goal of a large-array splice with maximum loss below 0.5 dB.

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